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Meeting Minutes

Program Review Meeting

Contract N00014-91-C-0128

Alcoa Technical Center

1993 October 20

A meeting was held at the Alcoa Technical Center (ATC) on 20 October 1993 to review progress and plans for ONR (Office of Naval Research) Contract N00014-91-C-0128, "Role of Microstructure on Fatigue Durability of Aluminum Aircraft Alloys". Those present were:

R. J. Bucci (ATC)
A. J. Hinkle (ATC)
H. J. Konish (ATC)
J. Liu (ATC)
P. E. Magnusen (ATC)
S. M. Miyasato (ATC)
M. A. Przystupa (UCLA)
A. K. Vasudevan (ONR)

Discussion covered a wide range of technical and programmatic issues. For the sake of clarity, the points raised during the course of the discussion are divided into four major areas, program administration, program direction, technical progress, and action items. The detailed topics covered in these four areas are described in the following sections.

Program Administration

Dr. Vasudevan emphasized the importance of contractual reporting requirements. Both ATC and UCLA, which are joint contractors on this program, are required to submit three quarterly progress reports, due 15 April , 15 July, and 15 October, as well as an annual report covering the entire calendar year, due 15 January. Quarterly reports should be approximately 10 to 15 pages long, including any appended figures and tables; the annual summary should be between 20 and 25 pages in length, again including figures and tables. ATC will bring its reporting practices into compliance with this system by submitting an annual summary report for calendar year 1993 which will cover program activities since the comprehensive program interim report [1] issued in April 1993 and thereafter following the prescribed reporting requirements and schedule.

Supplementary reporting of program activities is appropriate, though not required on any formal schedule. Supplementary reports include input for the Annual Letter Report of ONR's Applied Research and Technology Directorate, Technical papers and presentations reflecting work performed under the contract, and contractor reports covering activities performed as contract tasks. ATC offered to provide an internal report describing ATC work on characterization of particle distributions in thick plates of aluminum alloy 7050 [2] and a copy of the viewgraphs presented at the program review meeting held in August of 1993. (These reports were sent to Dr. Vasudevan on 21 October 1993 [3].)

Several budgetary issues were raised during the course of the meeting. Dr. Vasudevan requested a summary of the current budgetary status of the ATC contract, based on the current authorized funding limit of $631K. This summary is provided as Attachment A to these minutes.

Dr. Vasudevan also noted that the remaining program funding of $157K which has not yet been authorized may be available for work in calendar year 1994. He agreed to check on the status of this additional funding and provide his findings to ATC as a basis for planning additional program activities. He further offered to confirm that the contract termination date of December, 1995, remains in effect, although it was recognized by all parties that the contract will be terminated for all practical purposes when authorized funding has been exhausted and the final report has been submitted.

Dr. Vasudevan requested clarification of the interaction between ATC and UCLA on the various tasks of the program. An overview of program activities and the organization(s) involved in them is shown in Attachment B. He also requested information on any work complementary to the actual contract activities which was being or had been performed at ATC under internal Alcoa or other contract funding. A description of complementary activities and the scope of support provided to the ONR contract is provided as Attachment C.

Dr. Vasudevan requested any information regarding complementary work being pursued by the U. S. Air Force and/or NASA. A cooperative program between Alcoa and the Air Force (WPAFB) has been carried out (Attachment C), and ATC has been discussing follow-on work with the Air Force. The implications of the microstructural modeling process are fully compatible with the proposed Air Force protocol for assessing component durability, and improved thick product forms have been included in the current road map for Air Force research and development programs. NASA has expressed informal interest in the work, and has implemented an internal R&D effort to develop methods for incorporating early stage crack growth processes into life prediction methodology.

Program Direction

The ATC perception of this program was provided in the form of two flow charts, provided as Attachment D. The first of these flow charts indicates the manner in which ATC perceives the integration of its various tasks in this program and the end result which is expected. A path for integrating the fundamental activities being performed under this contract into the broader context of structural integrity enhancement is shown in the second flow chart. These flow charts together describe a process through which the Navy can capture the optimal value of the work it is presently supporting.

One cost-effective option for continuation of the current program was identified during the course of the meeting. This option is based on incorporation of a new variant of alloy 7050 thick plate which is to be fabricated at Alcoa's Davenport works in the near future. This material is expected to exhibit improvements in fracture toughness, fatigue crack growth (under high ΔK and spectrum loading conditions), short transverse ductility, and capacity for cold working of holes. Improved corrosion resistance and corrosion fatigue properties are also anticipated on the basis of results being developed under the corrosion fatigue program of the joint NASA/FAA investigation of aging aircraft. It is planned to perform initial testing of this material to confirm these expected advantages under internal support at ATC in the first half of 1994. Since this material is a logical element of the variant chain already incorporated into the ONR program, it was suggested that modest ONR support for modeling and documentation activities would allow the available test data to be more fully exploited.

The ATC perception of the current deliverables for this program was presented to Dr. Vasudevan. These deliverables define the goals toward which ATC has been working. In order to assure that ATC efforts are consistent with ONR expectations, Dr. Vasudevan agreed to review these deliverables and provide comments to ATC.

Dr. Vasudevan indicated that he expects to be pursuing an extension of the current program during the spring of 1994. He requested assistance from his contractors in both identifying future program directions for further work and in defining long-range benefit of this program to end users in the Navy and elsewhere. It was suggested that the current fundamental work is now approaching a state which will permit paper studies of trial structural applications to be performed, and that such studies would be a logical focus for a program extension. Such work would necessarily require participation of manufacturers

(e.g., airframers) and end users, however. It was agreed that ATC would suggest some candidate airframer participants for a paper study activity. Dr. Vasudevan offered to arrange two meetings, one with key personnel from ONR and other Navy facilities (e.g., NAWC) and a follow-on meeting with Navy and airframer personnel. The intent of both meetings is to obtain wider exposure for the work that has been done and to build support for follow-on application phases of activity. It was agreed that ATC would participate in these meetings by presenting the work that has been done and explaining the path by which that work could be employed by the Navy to enhance structural integrity.

Dr. Vasudevan also observed that the perceived value of the work would be enhanced by demonstrating the broadest possible scope of potential applicability. Possible ways of doing so were discussed. One potential use of the technology is in the USAF program to evaluate AL-Li alloy C255 as a candidate replacement material for F16 bulkheads. Lessons learned in the ONR program will contribute to the development of fabrication processes for this activity, being performed by Alcoa under subcontract to the Lockheed Fort Worth Company. The development of improved thick product forms of alloy 7050 was also noted as a use of the basic technology. The potential for dual military and civilian use of the technology as another way of extending the value of this technology was also discussed. Additional uses of the technology are addressed in Attachment E.

Technical Progress

Much of the discussion of the technical progress revolved around the details of the modeling process. The model itself is a reasonably conventional fatigue crack growth model in which a crack is assumed to initiate at a microstructural inhomogeneity such as a pore or particle. Because the model is based on conventional fracture mechanics concepts, it is compatible with the large existing technology infrastructure that has been developed in this field. Thus, although the emphasis of the current work is placed on microstructural inhomogeneities, the basic analytical/modeling framework would apply equally to larger inhomogeneities such as manufacturing imperfections and service damage such as scratches and corrosion pits.

Crack initiation is not explicitly treated in the current version of the analytical model. Rather, initiation is incorporated into the stress intensity factor solution for the model, which is defined for a crack emanating from a particle. This particular stress intensity factor model can be used to define the size of a plastic zone at the particle boundary, which is treated as the initial crack size. Although this approximation leads to results which agree well with experimental data, more rigorous treatment of the crack initiation process is planned. Crack initiation in aluminum alloy 7050 is currently being addressed under a cooperative program between ATC and Purdue University (Professor A. F. Grandt, Jr.) and results of this program will ultimately be incorporated into the analytical crack growth model.

Other results from the ATC/Purdue cooperative program complement those of the ONR program. For example, results obtained at Purdue suggest that the fatigue growth behavior of a macrocrack is not affected by microstructural quality. This observation suggests that the improved fatigue performance obtained with specimens of material having improved microstructural quality is due to the reduced number and size of crack initiators and/or slower microcrack fatigue growth rates. The limited role of macrocrack fatigue growth rates in the overall fatigue performance of a specimen has been further emphasized by results obtained from a cooperative program between ATC and the Air Force. In this program, specimens of varying microstructural quality were tested to failure under spectrum fatigue loading conditions. It was conclusively demonstrated that the level of microstructural quality had an effect on specimen life despite the presence of as-machined

holes. Neither large structural stress concentrations nor spectrum loading conditions were significant enough to mask the effects of microstructural quality.

The results obtained in the ONR program indicate that various types of microstructural features fall into a definite hierarchy of severity. Thus, different types of microstructural features affect specimen fatigue life to varying degrees. Dr. Vasudevan suggested that the relationship between feature type and fatigue lifetime could be clarified by presenting the results in the form of a microstructure/performance map. Work by Ashby and others may provide a suitable basic framework on which to develop such a map.

A number of the findings developed to date were identified as "lessons learned". These findings constitute a thumbnail sketch of program results and are the key conclusions reached to date. The specific conclusions defined as "lessons learned" are:

- Microstructural features have an effect on specimen fatigue life even in the presence of intentional or inadvertent stress concentrations. Manufacturing inhomogeneities do not dominate the effects of microstructural features.

- Fracture mechanics techniques can be used to predict the effects of microstructural features on specimen fatigue life.

- Types of microstructural features can be ranked according to the severity of their effect on specimen fatigue life.

- The fracture mechanics model of the effects of microstructural features can be combined with probabilistic methods to assess the structural implications of microstructural features and machining consequences. The probabilistic fracture mechanics model can be used to design structures on a risk management basis.

- Realization of improvements in material performance may require some changes in the perceptions and practices currently used for design.

Action Items

A significant number of action items were identified during the course of the meeting. These action items, some of which are met by these minutes and the attachments, are listed below in summary form.

- Alcoa will provide a summary of the overall financial status of the program. (This commitment is satisfied by the data provided in Attachment A.)

- Alcoa will provide a summary of interactions between ATC and UCLA on this program. (This commitment is satisfied by the data presented in Attachment B.)

- Alcoa will provide a summary of efforts supported by internal Alcoa and/or other external sources which complement the ONR program. (This commitment is satisfied by the data presented in Attachment C.)

- Alcoa will recommend candidate airframers for participation in the structural application phases of this effort.

- Alcoa will send a package of program documents to Gary Halford (NASA/LeRC), Jim Rudd (WPAFB), and Jim Newman (NASA/LRC).

- Dr. Vasudevan agreed to check on the expected future status of this program and advise ATC concerning the availability of additional funding and the current date planned for contract termination.

- Dr. Vasudevan will arrange for a program review with key Navy personnel from both ONR and organizations more directly focused on end user needs.

- Dr. Vasudevan will review the ATC perception of program goals and deliverables and provide feedback to assure consistency of ATC efforts and ONR expectations.

References

1. Brockenbrough, J. R., R. J. Bucci, A. J. Hinkle, J. Liu, P. E. Magnusen, and S. M. Miyasato, "Role of Microstructure on Fatigue Durability of Aluminum Aircraft Alloys," Progress report for Contract N00014-91-C-0128, Product Design and Mechanics Division, Alcoa Technical Center, Alcoa Center, Pa., 15 April, 1993.

2. Miyasato, S. M., P. E. Magnusen, and A. J. Hinkle, "Constituent Particle Distributions in 7050 Thick Plate," Report No. 57-92-31, Product Design and Mechanics Division, Alcoa Technical Center, Alcoa Center, Pa., 2 December, 1992.

3. Magnusen, P. E. , "ONR Contract No. N00014-91-C-0128, Role of Microstructure on Fatigue Durability of Aluminum Aircraft Alloys," Letter to A. K. Vasudevan (ONR), Alcoa Technical Center, Alcoa Center, Pa., 21 October, 1993.

ATTACHMENT A

SUMMARY FINANCIAL STATUS

A summary of total monthly and cumulative expenditures charged to ONR contract N00014-91-C-0128 from September, 1991, through December, 1993, is shown in Table A-1. Also shown are total budget ceilings for the contract during this period and corresponding monthly budgets, which are simply the linear average of the then-current authorized budget ceiling divided by the number of months during which it was originally defined to be effective. Cumulative cost and budget data, together with the corresponding budget ceilings, are also shown in graphical form in Figure A-1.

Table A-1. Cost and Budget Summary for ONR Contract N00014-91-C-0128

Month	Monthly Cost ($)	Cumulative Cost ($)	Monthly Budget ($)	Cumulative Budget ($)	Budget Ceiling ($)
September, 1991	$0	$0	$21,875	$21,875	$350,000
October, 1991	$0	$0	$21,875	$43,750	$350,000
November, 1991	$5,699	$5,699	$21,875	$65,625	$350,000
December, 1991	$3,721	$9,420	$21,875	$87,500	$350,000
January, 1992	$12,635	$22,055	$21,875	$109,375	$350,000
February, 1992	$11,610	$33,665	$21,875	$131,250	$350,000
March, 1992	$15,356	$49,021	$21,875	$153,125	$350,000
April, 1992	$13,286	$62,307	$21,875	$175,000	$350,000
May, 1992	$56,382	$118,689	$21,875	$196,875	$350,000
June, 1992	$13,309	$131,998	$21,875	$218,750	$350,000
July, 1992	$27,730	$159,728	$21,875	$240,625	$350,000
August, 1992	$44,882	$204,610	$21,875	$262,500	$350,000
September, 1992	$30,458	$235,068	$21,875	$284,375	$350,000
October, 1992	$23,838	$258,906	$21,875	$306,250	$350,000
November, 1992	$16,395	$275,301	$21,875	$328,125	$350,000
December, 1992	$25,871	$301,172	$21,875	$350,000	$350,000
January, 1993	$32,338	$333,510		$350,000	
February, 1993	$42,552	$376,062		$350,000	
March, 1993	$18,703	$394,765		$350,000	
April, 1993	$19,931	$414,696	$26,667	$376,667	$510,000
May, 1993	$12,320	$427,016	$26,667	$403,334	$510,000
June, 1993	$14,591	$441,607	$32,524	$435,858	$631,000
July, 1993	$26,015	$467,622	$32,524	$468,382	$631,000
August, 1993	$18,547	$486,169	$32,524	$500,906	$631,000
September, 1993	$9,433	$495,602	$32,524	$533,430	$631,000
October, 1993		$495,602	$32,524	$565,954	$631,000
November, 1993		$495,602	$32,524	$598,478	$631,000
December, 1993		$495,602	$32,524	$631,002	$631,000

The cost and budget data shown in Table A-1 and Figure A-1 are essentially self-explanatory, except for the budget gaps indicated at the beginning of calendar year 1993.

The gaps in authorized budget for this period were due to a delay in funding authorization. Work was continued at risk during this period, despite the lack of formal funding authorization, to assure that the momentum of the technical progress would not be lost.

It should be noted that cumulative ATC expenditures have been well below the target levels throughout the course of this program. It is only during the budget transition period at the beginning of 1993 that ATC costs exceeded budget targets. Current cumulative expenditure levels are slightly more than one month behind projected levels.

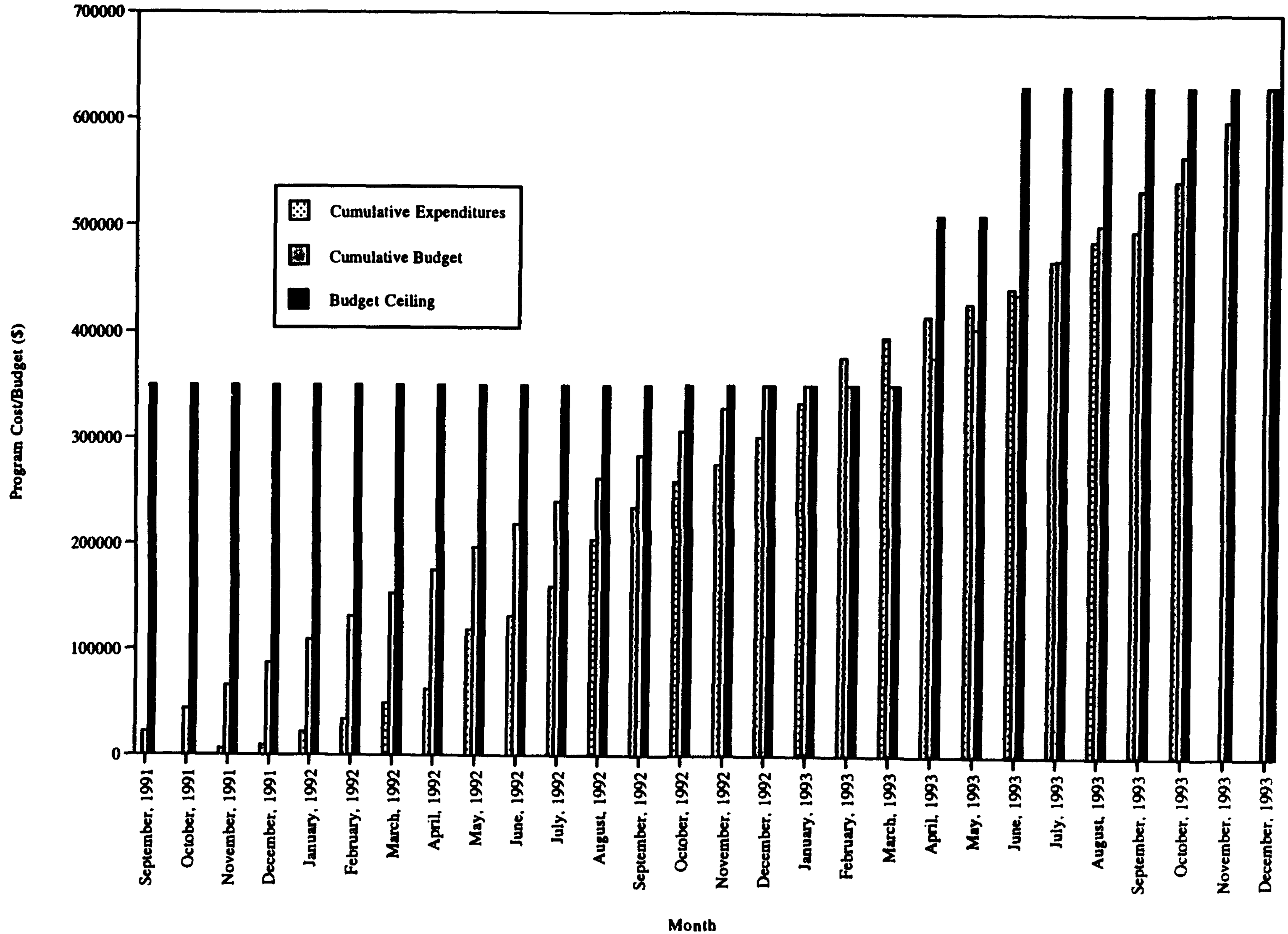

Figure A-1. Cumulative Cost and Budget Status for ONR Contract N00014-91-C-0128D.

ATTACHMENT B

ATC/UCLA INTERACTION

Interactions between ATC and UCLA on work sponsored by ONR under contract N00014-91-C-0128 are designed to exploit the different strengths of the two organizations and minimize duplication of effort, while also providing some freedom to explore alternative approaches to the overall problem. The interactions are indicated in Table B-1, where the overall scope of the program is divided into four major tasks. The first task, that of creating a fatigue performance data base for the different variants of alloy 7050, has been largely performed at ATC, due to the availability of prior data and material for further testing. All results in the fatigue data base have been shared with UCLA participants, however, who therefore have the opportunity to perform there own assessments of trends and implications and select those data sets which are of most interest to them.

The second and third main tasks of the program, definition of fracture mechanisms and characterization of microstructural features, have been carried out in parallel by both ATC and UCLA. Work on these two tasks has been performed in a highly interactive fashion, with personnel from both organizations sharing in each step of every sub-task. Both organizations have carried out extensive amounts of microstructural examination and accompanying evaluation to define fracture mechanisms and microstructural crack initiators. Similarly, both organizations have participated in developing quantitative models of microstructural features. Close coordination and cooperation between the two organizations has minimized duplication of effort and optimized exchange of information between the two organizations on these two tasks.

The fourth main task of the program, development of probabilistic structural integrity models, is also an area in which both ATC and UCLA have been active. The models being developed by both organizations differ somewhat, however, and interaction between the two groups has thus been somewhat more limited on this task than on the others of the program. The model being developed by ATC is based on probabilistic fracture mechanics methods. Critical microstructural features are modeled as macroscopic cracks and their subsequent growth under fatigue loading conditions is analytically described. The modeling approach used by UCLA is more stochastic in nature and is more focused on the microscopic details of the material. Although a potential interface between the two models may well be developed in time, the models are currently being developed as distinct and separate entities.

Table B-1. ATC/UCLA Interactions.

Task	Sub-task	Step	ATC	UCLA
Create fatigue data base	Review existing data	Retrive data	√	
		Assess validity of data	√	
		Store data in database	√	
	Generate necessary additional data	Define additional data requirements	√	
		Procure material	√	
		Fabricate specimens	√	
		Test specimens	√	
		Assess validity of data	√	
		Store data in database	√	
	Examine implications of data	Define data trends	√	
		Select data sets for further examination	√	
		Document results	√	
Define fracture mechanisms	Fractography of fatigue specimens	Select fatigue specimens for characterization	√	√
		Prepare specimens for fractography	√	√
		Perform fractography	√	√
		Evaluate results	√	√
	Define hierarchy of microstructural crack initiators	Rank fractography results according to material pedigree and specimen type	√	√
		Define critical microstructural features	√	√
		Document results	√	√
Characterize microstructure	Random plane metallography	Prepare metallographic specimens	√	√
		Perform quantitative metallography	√	√
		Define distributions of microstructural features	√	√
	Quantify and apply results	Develop methods to calculate extreme value disributions of microstructural features	√	√
		Correlate extreme value distributions of microstructural features with fractography results	√	√
Develop model	Probabilistic structural integrity model	Define microcrack model	√	√
		Predict specimen life based on fractographic measurements	√	√
		Predict specimen life based on random plane metallography	√	
		Compare calculated results to test data	√	√
		Revise model as necessary	√	
		Perform sensitivity studies	√	
		Implement probabilistic considerations	√	
		Document results		

ATTACHMENT C

COMPLEMENTARY PROGRAMS AND ACTIVITIES

Alcoa's interest in developing a quantitative link between material microstructure and material performance dates back to the mid-1970's (Figure C-1). While a significant amount of work was performed during the early stages of Alcoa's involvement in this area, much of it was directly focused on control of product quality. Little effort was expended on developing fundamental understanding and quantitative models of failure processes and mechanisms until approximately 1988.

The microstructural modeling work directly supported by ONR has been the beneficiary of numerous complementary efforts conducted by Alcoa and other organizations. Alcoa has invested a total of approximately $3400K of internal funding in areas related to the ONR program over the period from 1988 to 1993, inclusive. A breakdown of these expenditures is provided in Table C-1.

The complementary Alcoa effort is divided into three major categories, base technology, a cooperative program with the Air Force, and a new product development effort. Of these three, the base technology effort has been the largest by a substantial margin. The four tasks conducted under the base technology program have provided the fundamental basis for the work supported by ONR and have also provided supplementary support for some of the modeling activities performed as part of the ONR-sponsored effort.

Alcoa has also conducted a cooperative program with the Air Force (WPAFB) on thick product forms with improved microstructural characteristics. Alcoa provided material for spectrum loading fatigue tests performed by WPAFB, and participated in the material characterization and test evaluation phases of the program. In addition to the material costs and Alcoa participation, both supported by Alcoa internal funding, the Air Force provided testing effort estimated at $300K.

The third major activity which has directly contributed to the ONR-sponsored work is a new product development effort. This effort has been focused on exploiting the results of more fundamental activities to obtain a thick product form of superior quality to the incumbent. It is, for Alcoa, the beginning of an effort to realize a competitive advantage from the fundamental modeling and evaluation efforts.

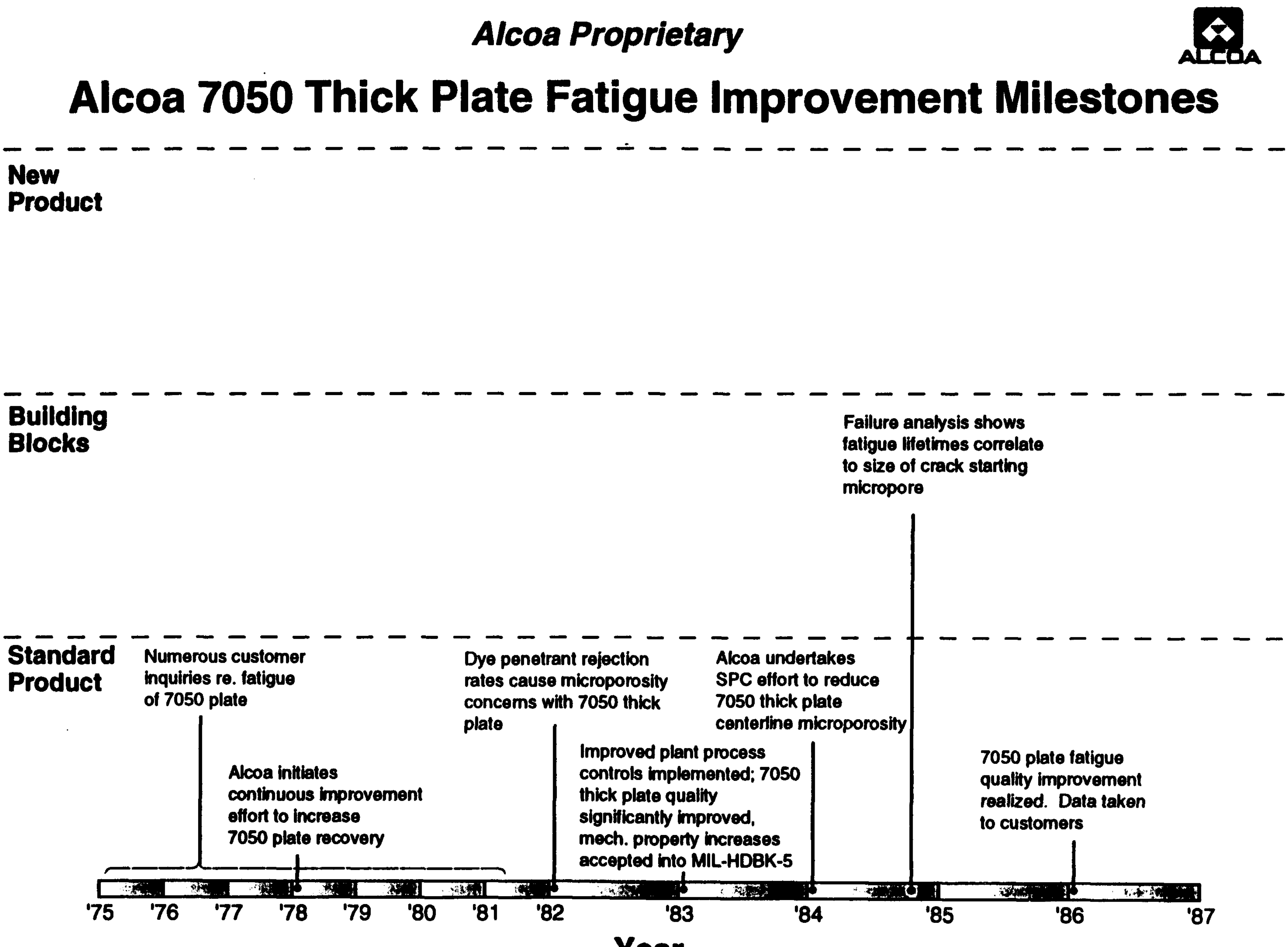

Figure C-1a. Evolution of Alcoa Activities Related to Understanding the Effects of Microstructural Characteristics on Material Performance.

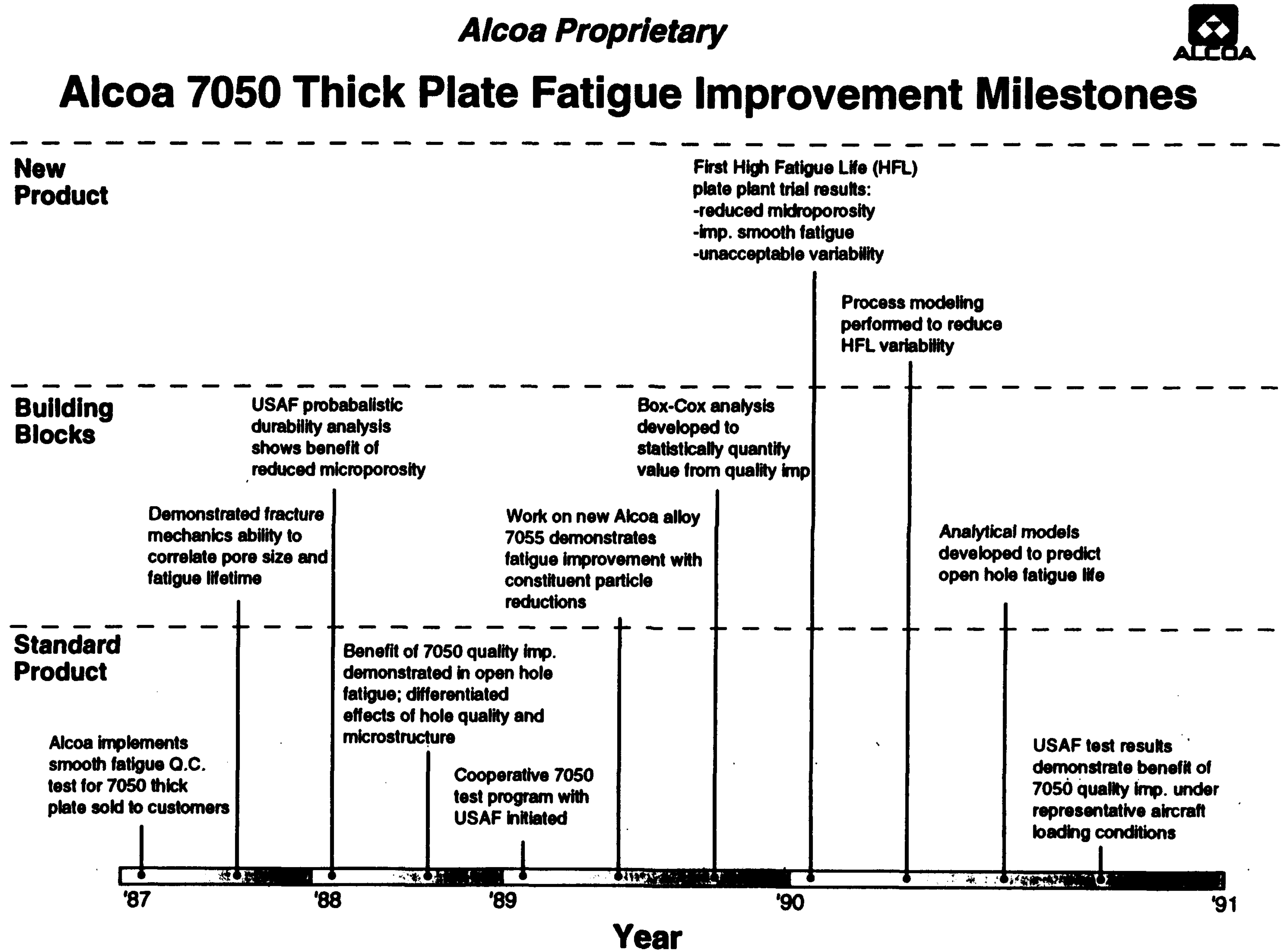

Figure C-1b. Evolution of Alcoa Activities Related to Understanding the Effects of Microstructural Characteristics on Material Performance (cont.)

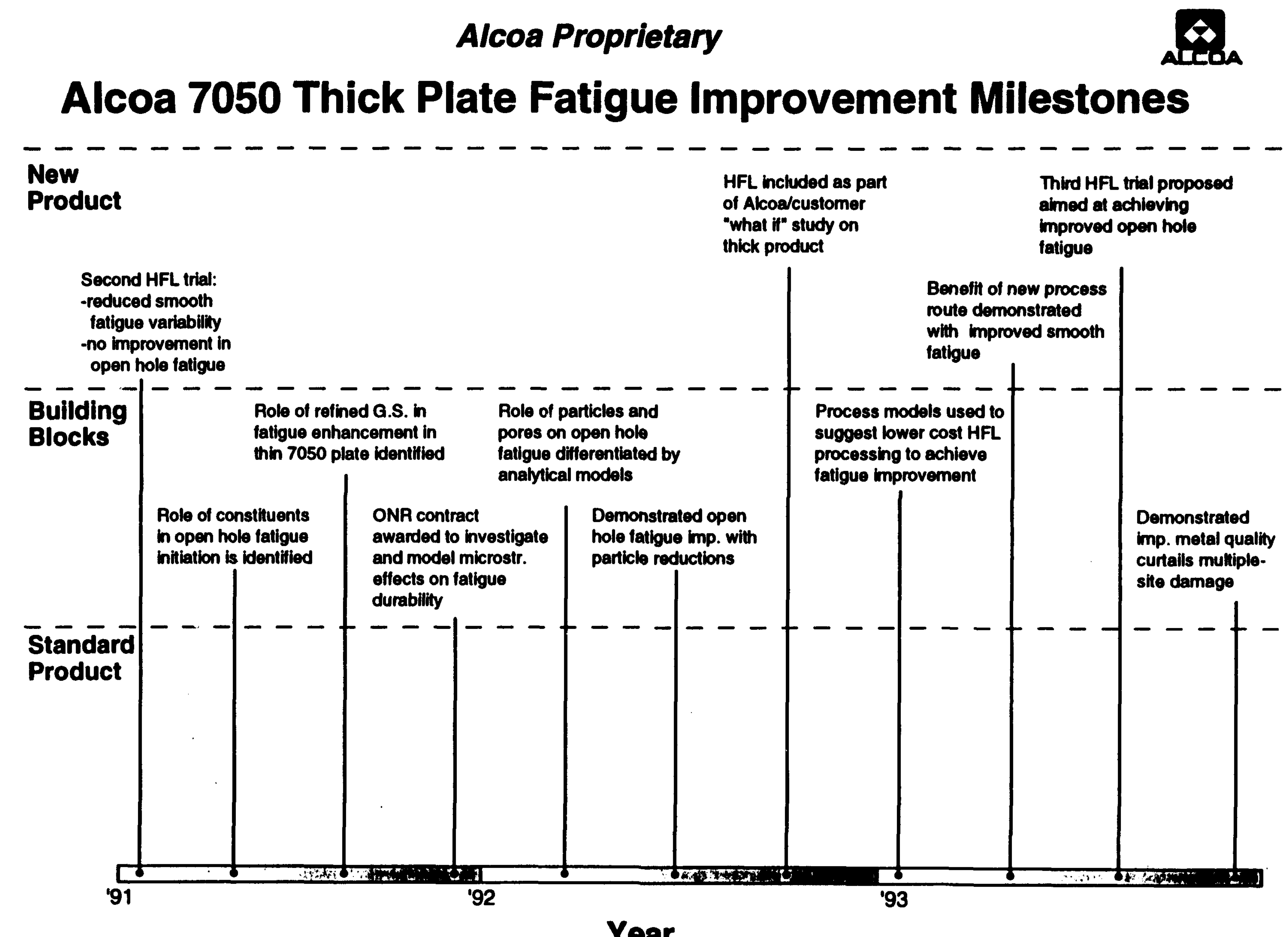

Figure C-1c. Evolution of Alcoa Activities Related to Understanding the Effects of Microstructural Characteristics on Material Performance (cont.).

Table C-1. Alcoa Internally Funded Work Complemetary to ONR Program.

Technology Area	Activity	Alcoa Internal Funding Expenditures						
		CY 1988	CY 1989	CY 1990	CY 1991	CY 1992	CY 1993	Totals
Base Technology	Test methodology development and material characterization	$32K	$89K	$50K	$23K	$20K	$11K	$225K
	Understanding and modeling of material performance	$420K	$367K	$420K	$322K	$252K	$210K	$1991K
	Understanding effects of microstructure on fatigue performance	$0K	$21K	$14K	$42K	$56K	$56K	$189K
	Development of probabilistic analysis methods	$0K	$0K	$28K	$28K	$28K	$28K	$112K
Air Force Cooperative Program	Production and evaluation of material	$24K	$5K	$0K	$0K	$0K	$0K	$29K
	Material characterization and ATC participation	$75K	$108K	$76K	$35K	$30K	$0K	$324K
New Product Development	Process modeling	$50K	$50K	$50K	$50K	$50K	$42K	$292K
	Development of high-fatigue-life plate	$0K	$0K	$0K	$138K	$100K	$10	$248K
Totals		$601K	$640K	$638K	$638K	$536K	$357K	$3410K

ATTACHMENT D

SUMMARY PROGRAM PLAN

A summary of the ATC program under ONR contract N00014-91-C-0128 is shown in Figure D-1. This chart describes the principal activities which have been performed or are planned under the existing program, and the manner in which they are integrated into a single coherent program.

The basic premise of th: program is that differences in the microstructural features of a single given material, achieved by varying processing conditions, would yield differences in fatigue performance which could be quantitatively predicted. The material chosen as the subject of the exercise was aluminum alloy 7050, although the work is by no means applicable only to this alloy or to aluminum.

Review of the task elements defined in Figure D-1 clearly indicates that the principal thrust of the ATC effort is focused on development of a fundamental model for predicting material response. It began with an evaluation of historical Alcoa data, which was intended to provide a basis for comparison of new variants of the subject material. This evaluation was completed in the early phases of the contract effort.

The second step of the investigation was to define a severity hierarchy of microstructural features in terms of their impact on fatigue performance. This process is an ongoing one which has already undergone some revision as a result of accumulating data. The changing nature of the severity hierarchy is brought about by the fact that, while macrostructural features of a fatigue specimen do not completely mask the effects of microstructure, they can affect the relative severity of different types of microstructural features.

The results of the first two steps of the investigation form a basis for the quantitative modeling work. This modeling activity proceeds along two parallel and interactive paths, one of which is quantification of microstructural features and confirmation of a link between differences in microstructural feature populations and fatigue performance. The parallel path is development of a predictive model which can be used to link the quantitative microstructure descriptions with observed specimen fatigue lives.

The validity of the model must be confirmed by comparison with test data, if the end result is to be anything more than a mathematical curiosity. Comparisons of modeling predictions and test data are therefore provided in the development plan. Such comparisons serve a dual purpose, as they not only serve to define the readiness of the model for further use but also indicate the need and path of further model development. The model must eventually reach a stage at which it is sufficiently developed to support more widespread use. At this point, although further refinement of the model will likely remain warranted, the primary emphasis of the development work will shift from model development to model application. As the initial objectives of the program have then been met, further effort will be carried out under one or more follow-on programs.

The overall flow of the current program and follow-on tasks is shown in Figure D-2. The first two blocks of this diagram correspond to the current program, which is focused on development of a quantitative model and confirmation of model validity. These activities, when successfully concluded, form the basis for realistic structural applications of the model. The envisioned process for such applications would begin with one or more paper studies in which the microstructural model would be applied to one or more selected structural elements with the intent of demonstrating a tangible advantage in structural performance as a results of microstructural control.

These studies would require involvement on the part of airframers or other hardware manufacturers and selected government organizations. The involvement would cover a number of areas, including selection of suitable structural elements for the paper study,

definition of service conditions, and participation in the evaluations of structural performance. A primary objective of this participation would be to develop familiarity with the microstructural model and its application among potential users, in order to raise their comfort level with the approach and to help overcome resistance based on conventional flaw tolerance design approaches.

As the initial paper studies proceed, it is expected that one or more suitable candidate components for physical validation of the model predictions will be identified. Fabrication and testing of such components is the final gateway to deployment of the concept and realization of the benefits now being demonstrated on a laboratory scale.

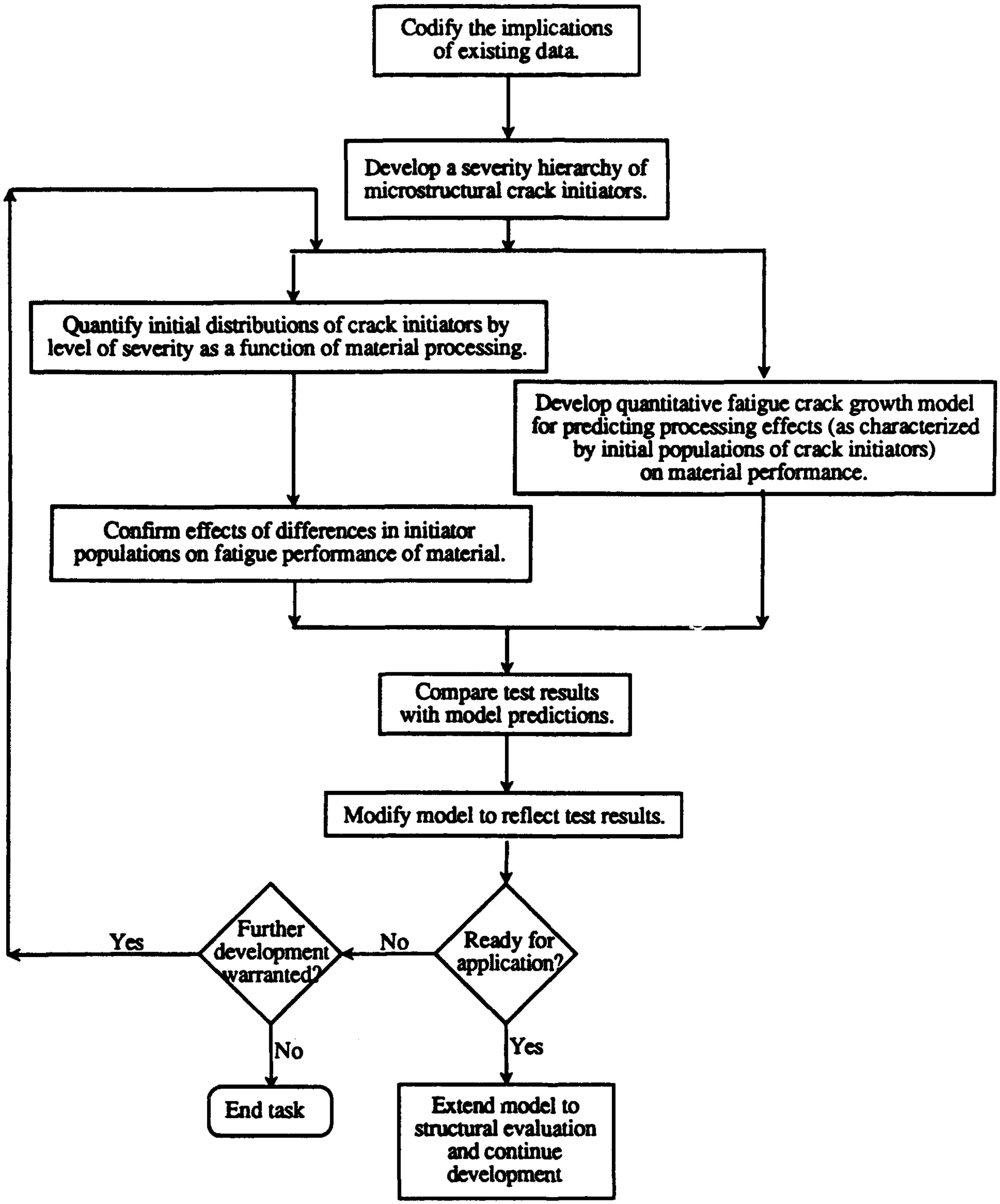

Figure D-1. Flow of ATC Effort Under ONR Contract N00014-91-C-0128.

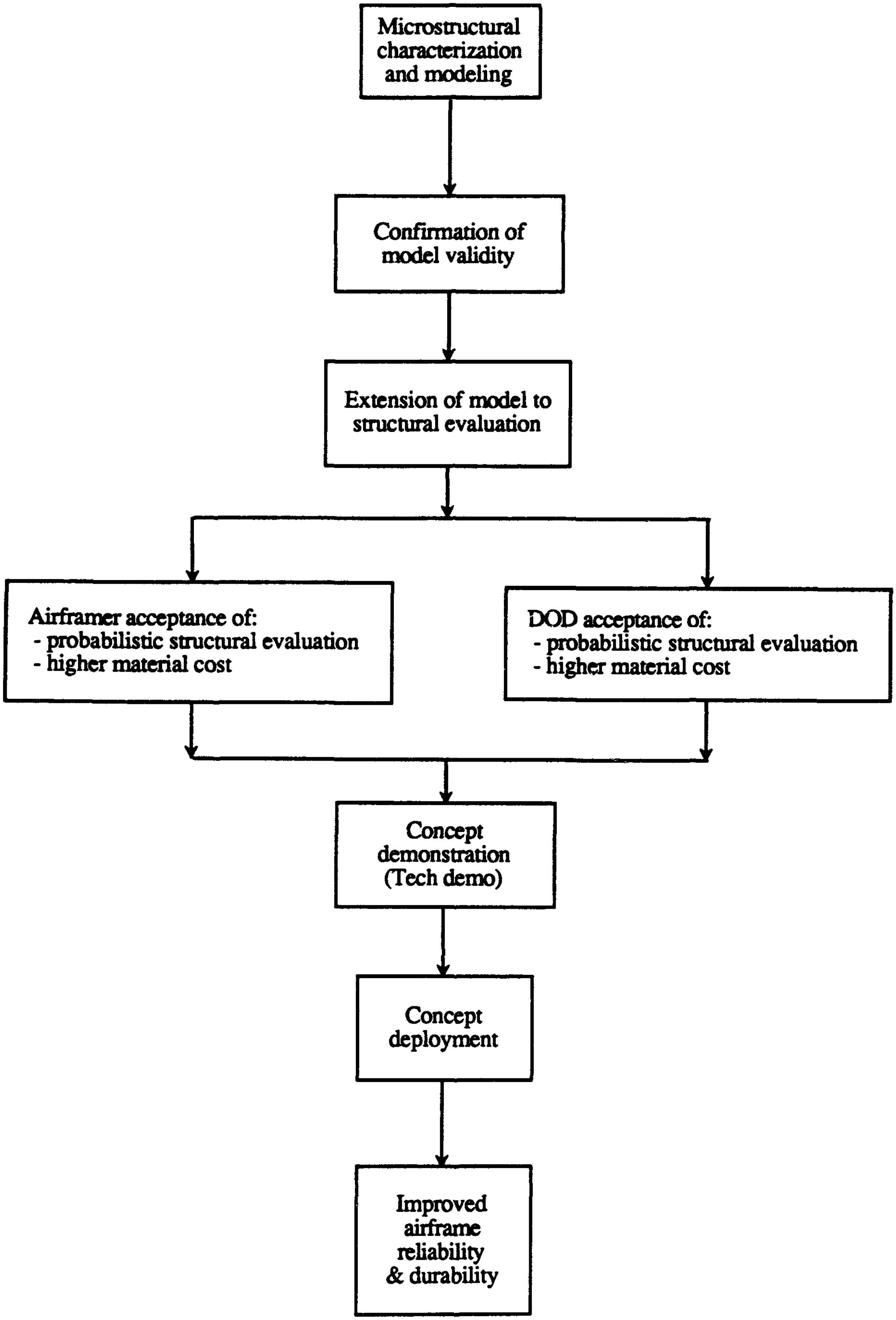

Figure D-2. Scenario for Incorporating Model Development into Structural Design and Evaluation.

ATTACHMENT E

POTENTIAL TECHNOLOGY APPLICATIONS

Much of the effort to date which has been devoted to modeling the effects of microstructure on material performance has been focused on the development of basic technology. Although continuing development will certainly be required, the technology is now sufficiently mature to allow projection of some potential applications. Three general paths for such applications are envisioned.

The first major application path for the microstructural modeling technology is that of material design. The ability to relate microstructure to macrostructural performance of the material allows the effects of composition and/or processing to be inferred without the cost and time requirements of a full-scale test program. Composition and process parameters which yield optimal mechanical properties of the finished material product form can thus be selected much more quickly and economically than is now the case. This technology is now being applied by Alcoa to develop improved thick plate products of an aerospace aluminum alloy.

Although the material basis for developing the microstructural modeling technology has been wrought aluminum alloys, the technology is expected to have a much broader field of application. While such wider application has yet to be conclusively demonstrated, it is certainly realistic to expect that the core technology will be applicable to non-wrought product forms such as castings. It is also reasonable to anticipate applicability of the basic modeling technology to other metallic materials. In the limit, the modeling technology might even prove applicable to ceramics and other high performance materials such as metal-matrix composites. These and similar technology extensions will require some additional development effort to establish material-specific elements of the microstructural model, such as appropriate severity hierarchies of microstructural features.

Although the model has been developed to assess changes in microstructure due to variations in material composition and processing, many of the basic concepts are expected to be applicable to other types of microstructural/macrostructural features as well. The fundamental modeling concepts could also be applied to material damage features introduced during fabrication, for instance. They might also be used to obtain a quantitative assessment of the implications of service-induced damage (e.g., scratches, corrosion pits) to the reliability and durability of a structural component.

The second major application path for the modeling technology is to structural design and evaluation. This path is needed to translate the performance gains demonstrated at the coupon specimen level to component improvements such as weight reduction, increased load carrying capacity, and/or increased component durability and reliability. Pursuit of this end goal is a task of some complexity, because current design practices do not lend themselves to full exploitation of the merits that can be achieved by improving the microstructural characteristics of the material. This situation is particularly evident in current design approaches for structural integrity, which are based on the assumed existence of a "rogue" crack. Since the presence of this crack is assumed at the onset of structural service, the advantages of reducing the size and number of crack initiation sites by microstructural control is unrecognized.

While protection against a defined "worst case" flaw must be maintained, the advantages of improved material performance can be obtained by applying probabilistic design approaches similar to that proposed by the Air Force. Use of such a design path allows the true merits of the material to be more explicitly taken into account, while providing a more realistic appraisal of the potential for failure from a macrocrack present at the beginning of service life. Designers must become familiar and comfortable with this approach before it will be used in structural design, however. Thus, a primary initial task in the structural

applications arena will be an educational one, directed toward achieving acceptance of more realistic design methods by equipment designers and manufacturers.

The third major application path for the technology is analogous to the second, but offers far more near-term potential in the current economic environment. As funding reductions delay development and procurement of new military hardware, increasing emphasis will be placed on extending the service lives of existing equipment. Service life extensions will require replacement of some structural components which are now nearing the end of their own service lives. For example, critical bulkheads and other structural members may be required to extend the operational lives of selected aircraft.

The technology being developed under this contract can be of immense value in life extension programs, because it allows low-cost improvement of existing materials. Thus, by applying the concepts developed under this program and complementary activities, it will be possible to develop directly substitutable components of the original alloy compositions which nonetheless exhibit significant performance benefits over the original components. In this way, it will be possible to enhance structural performance without re-qualification of the replacement components or the risk of developing new materials.